

November 29, 1996

TO: 832/Project Manager/G. L. Bland

FROM: 823/Mechanical Systems Engineer

SUBJECT: Vibration Environment of the EXDRONE Unmanned Aerial Vehicle

Abstract

The flight vibration environment of the EXDRONE vehicle was measured and analyzed to define its characteristics, provide information allowing frequency sensitive payload design, and to assist in the development of payload test specifications. A Telemetry system and an on board data recorder were flown on two EXDRONE missions to collect acceleration, vibration, attitude, thermal, and GPS data. Vibration testing was performed with this payload to record its frequency characteristics, and develop flight worthiness criteria. The payload's frequency response was factored out of the reduced data making it representative of the vehicle's input to the payload. The spectral data contains sharp primary peaks at frequencies that correspond to the engine speed. The peaks are present in a range from 94 to 115 hz corresponding to engine speed. The maximum peak was recorded in the Z (up) axis and had a magnitude of 3.3 g's. The magnitude of the data was dependent on the axis orientation with respect to the engine orientation. Launch shock loads reached 20 g's with a 10 g steady state acceleration during launcher travel. These results provide important information relating to payload design and qualification testing.

Introduction

The payload area of the EXDRONE Unmanned Aerial Vehicle (UAV) was instrumented to determine the characteristics of the flight environment. This environment has not previously been investigated. The EXDRONE vehicle has been in production for several years, and has been used by the military, primarily for surveillance purposes, including Desert Storm operations. The EXDRONE is a remote controlled flying wing with a wingspan of about eight feet. Enclosure 1 contains a picture of the EXDRONE while on the launcher. The payload area is in the center of the fuselage measuring 10 inches by 16 inches with a height of approximately 4 inches. The characteristics of the flight environment is critical information needed for designing payloads and developing test specifications. The vibration and frequency characteristics of the vehicle is also important when designing payload mounting hardware.

Instrumentation

A Telemetry (TM) system and a self contained Environmental Data Recorder (EDR) were installed in the UAV to measure the flight environment. The vehicle was instrumented with a variety of sensors that provided detailed information about the flight environment. Table 1 represents a listing of the instrumentation flown.

The Instrumentation Platform (IP) consisted of a 10 by 16 inch, 1/4 inch aluminum plate. The completed system weighed 15 pounds. All instrumentation hardware was mounted on this independent platform with the exception of the GPS antenna. This plate mounted on

Accelerometer # 1, (sn 247687), +40,-10" g", X axis, + forward, 2 k sps
Accelerometer # 2, (sn 357424), +5,-5" g", Y axis, lateral, + right, 2 k sps
Accelerometer # 3, (sn 357421), +5,-5" g", Z axis, + up, 1.5 k sps
Accelerometer # 4, (sn 357416), +20,-5" g", Z axis, + up, 2 k sps
EDR, 3 axis acceleration/vibration & temperature
GPS, position/velocity
Solar Sensor, Z axis, body attitude
Thermistors (3)

Table 1: EXDRONE Instrumentation

the two wooden rails along the internal sides of the fuselage. Enclosure 2 contains a picture of the IP mounted in the fuselage. A hole was cut out in the top of the aircraft allowing access to the instrumentation controls. A second hole allowed the s-band antenna to protrude outside the payload bay into the air stream. Two EDRs were used in the two test flights, one per flight. The EDR on the first flight was turned on prior to launch and collected continuous data sampling at 500 sps. The second EDR sampled at 4,800 sps and recorded data only when a one "g" trigger level was exceeded.

Testing

The IP was vibration tested to determine it's mechanical responses, evaluate the quality of data, and to qualify the hardware prior to flight. The tests included one "g" sine sweeps and a flat random spectrum at a level of .01 g^2/hz . The plate was mounted to the shaker in the same manner as mounted in the aircraft. The one "g" sine tests were used to determine the frequency response of the IP so that this information could be factored out of the flight data. All spectral analysis results have been corrected with the IP's response and are representative of input to the payload.

Results

Two instrumented flight operations were conducted on November 1, 1996 on the south end of Wallops Island. Flight velocities averaged between 60 and 80 mph as recorded with radar data. Good data was collected with the TM and the EDR units during both flights. Enclosure 3 shows a sample of TM acceleration data recorded during a maneuver. This TM data was passed through a low pass filter to emphasize the dc content of acceleration. This data reveals the aircraft is capable of exceeding 4 g's during flight maneuvers. Enclosure 4 contains the raw time history data collected with the EDR sampling at 4,800 sps. This data provided good frequency information from 0-2,000 hz. All other instrumentation performed nominally.

The vibration environments of concern are; low/high engine rpm while on the launcher, launcher travel, and low/high engine rpm while in flight. Payload survival concerns exist for all environments. Payload performance concerns are most critical during the flight en-

vironment. Enclosures 5 & 6 contain the X, Y, & Z acceleration spectrums for both low and high rpm while the vehicle was on the launcher. Enclosures 15-20 also present this information for each individual axes to provide higher acceleration resolution. Only the data below 500 hz is presented because the magnitude of vibration above this frequency is low by comparison. These graphs show a very clear spike, and harmonics that correspond to the engine speed. The peaks shift up and down with engine speed. The primary peaks are at 94 hz for low speed, and 115 hz for high engine speed. The Z axis (up) contains the highest magnitude of data. The X axis points out the right side and recorded higher vibration than the forward pointing (Y) axis.

Enclosures 7 & 8 contain time history data collected during launch. This vehicle is launched from a pneumatic launcher that generates high acceleration loads during launch. Two 20 msec shock loads were experienced by the UAV during launch. These shock loads are generated from engagement and dis-engagement of the launch fingers. The maximum launch shock load recorded was 19.6 g's at first motion. Enclosure 9 shows a close-up view of the time history representing this initial shock load. Enclosure 10 contains the Shock Response Spectrum (SRS) plot for launch. A high pass filter was used on this data to remove the input generated by the engine. The rail travel lasted for .25 seconds with a steady acceleration load of about 10 g's.

The low and high engine speed flight environments are represented in Enclosures 11 & 12. Enclosures 21-26 also present this information for each individual axes to provide higher acceleration resolution. The highest level of vibration occurred in the Z axis at high engine speed. At 115 hz, the acceleration level is 3.3 g's. The X axis (pointing right) recorded the next highest level at 2 g's with the Y axis recording the lowest amount of input. Higher harmonics are clearly visible. These results will vary depending on the characteristics (mass and frequency response) of the payload.

Power Spectral Density (PSD) analysis was performed on the data collected. The flight PSD information is presented in Enclosures 13 & 14 for the low and high engine speeds. There is clearly more vibration in the Z axis. Table 2 contains the flight "g" root mean squared (RMS) levels for low and high engine speeds.

Axis	Low Engine Speed	High Engine Speed
X	.6 g RMS	1.8 g RMS
Y	.7 g RMS	.7 g RMS
Z	4.3 g RMS	2.7 g RMS

Table 2: G RMS Levels from Flight

There is a higher g RMS value at low rpm in the Z axis, even though the magnitude of the peaks are greater during high rpm. At lower rpm the engine is not running as smoothly and there is more energy distributed throughout the spectrum.

Conclusions

The results obtained in the vibration analysis show that the majority of the vibration input

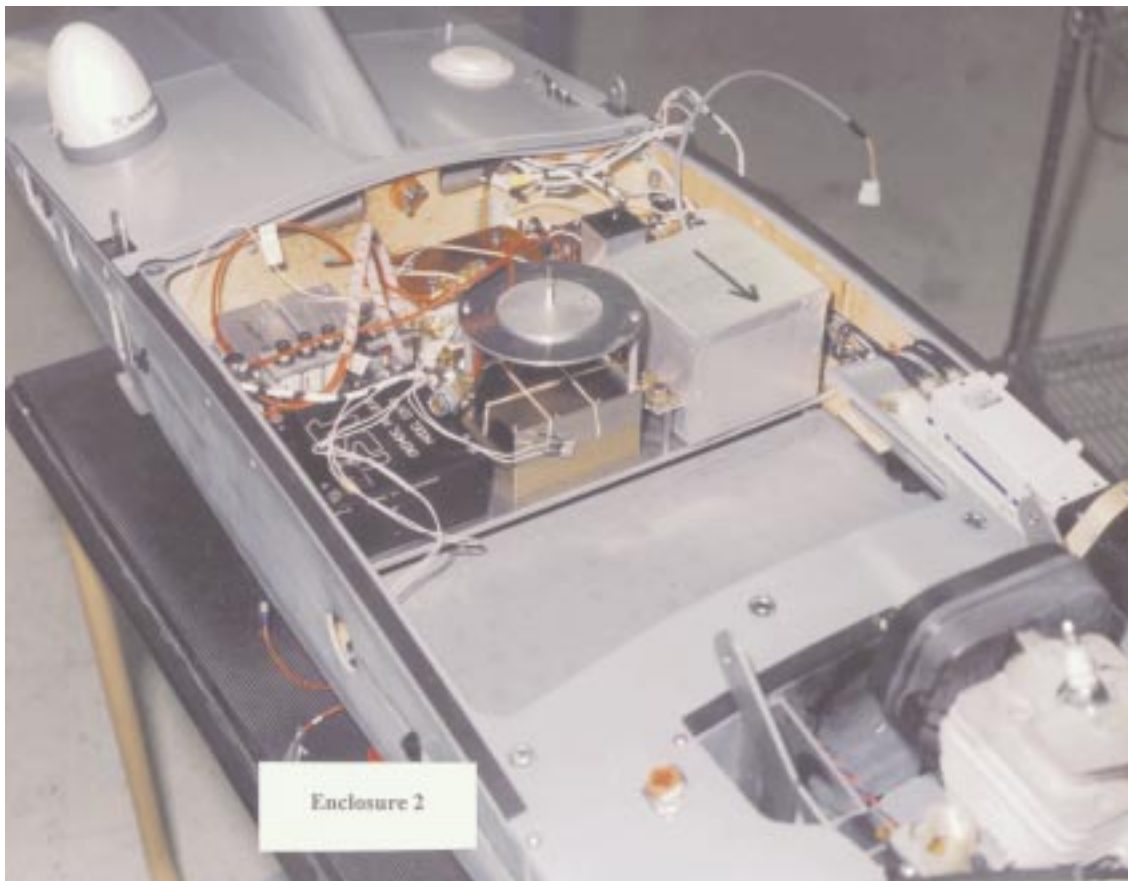
originates from the engine. There is very little aerodynamic buffeting. The peaks in the acceleration spectrum clearly follow the engine speed. The magnitude is greatest in the Z axis followed by the X (side pointing) axis. These axes experience more vibration because they are in plane with the rotational motion of the crankshaft. The Z axis was subjected to the highest vibration because it was also in plane with the up and down motion of the piston. The frequency content of the acceleration spectrum while the vehicle was on the launcher was very similar to the flight environment. The environment while on the launcher was less severe because the mass of the launcher absorbed energy from the vehicle.

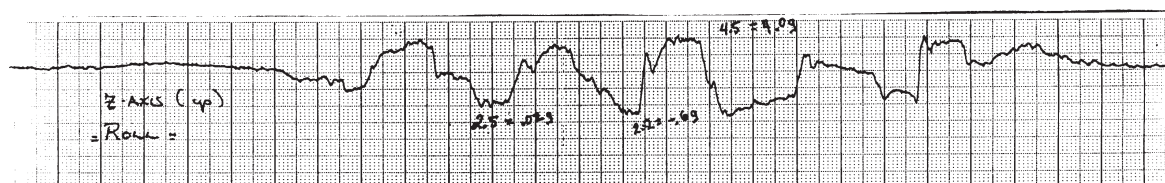
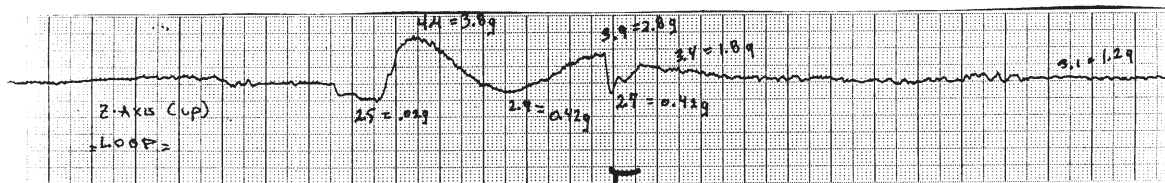
The data collected has provided important information about the flight environment of the EXDRONE vehicle. The maximum steady state acceleration loads recorded are about 4 g's for flight and 10 g's for launch. Launch shock loads of about 20 g's are also expected. The primary vibration input has a sinusoidal nature that corresponds to engine speed. The maximum loading of 3.3 g's at 115 hz occurred during high speed flight in the Z axis. These results will vary depending on the mass of the payload and it's frequency characteristics. The information presented will enable frequency sensitive designing and test specification development for the EXDRONE and it's payloads. Payload performance vibration testing can now be conducted on sensor hardware to determine how well it will perform under flight conditions. This will allow payload performance evaluation in a controlled environment and may minimize the requirement for flight testing.

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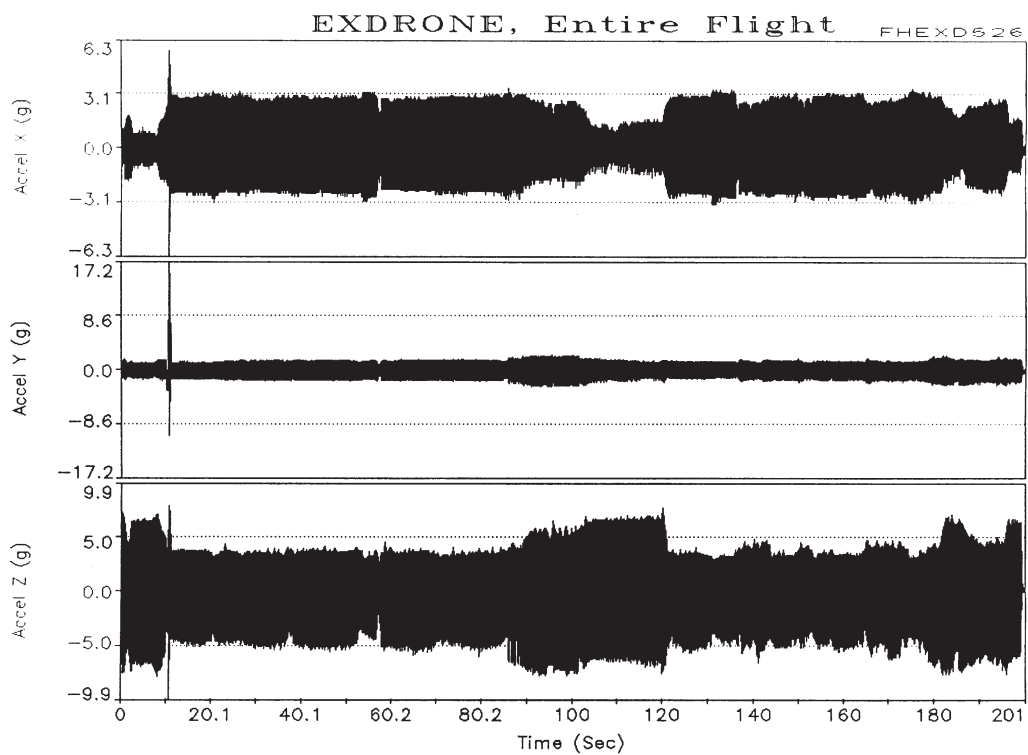
26 Enclosures

1. Picture of The EXDRONE on Launcher
2. Picture of Instrumentation Platform Installed in Fuselage
3. Telemetry Data, Maneuvers, Low Pass Filter
4. Acceleration Data Collected with EDR
5. Acceleration Spectrum, X Y & Z, Launcher, Low rpm
6. Acceleration Spectrum, X Y & Z, Launcher, High rpm
7. Time History, X Y & Z, Launch
8. Time History, Y axis, Launch
9. Time History, Y axis, First Motion Shock Load
10. Shock Response Spectrum Plot, High Pass Filtered, X Y & Z, Launch
11. Acceleration Spectrum, X Y & Z, Flight, Low rpm
12. Acceleration Spectrum, X Y & Z, Flight, High rpm
13. Power Spectral Density Plot, X Y & Z, Flight, Low rpm
14. Power Spectral Density Plot, X Y & Z, Flight, High rpm
15. Acceleration Spectrum, X axis, Launcher, Low rpm
16. Acceleration Spectrum, Y axis, Launcher, Low rpm
17. Acceleration Spectrum, Z axis, Launcher, Low rpm
18. Acceleration Spectrum, X axis, Launcher, High rpm
19. Acceleration Spectrum, Y axis, Launcher, High rpm
20. Acceleration Spectrum, Z axis, Launcher, High rpm
21. Acceleration Spectrum, X axis, Flight, Low rpm
22. Acceleration Spectrum, Y axis, Flight, Low rpm
23. Acceleration Spectrum, Z axis, Flight, Low rpm
24. Acceleration Spectrum, X axis, Flight, High rpm
25. Acceleration Spectrum, Y axis, Flight, High rpm
26. Acceleration Spectrum, Z axis, Flight, High rpm





Enclosure 3

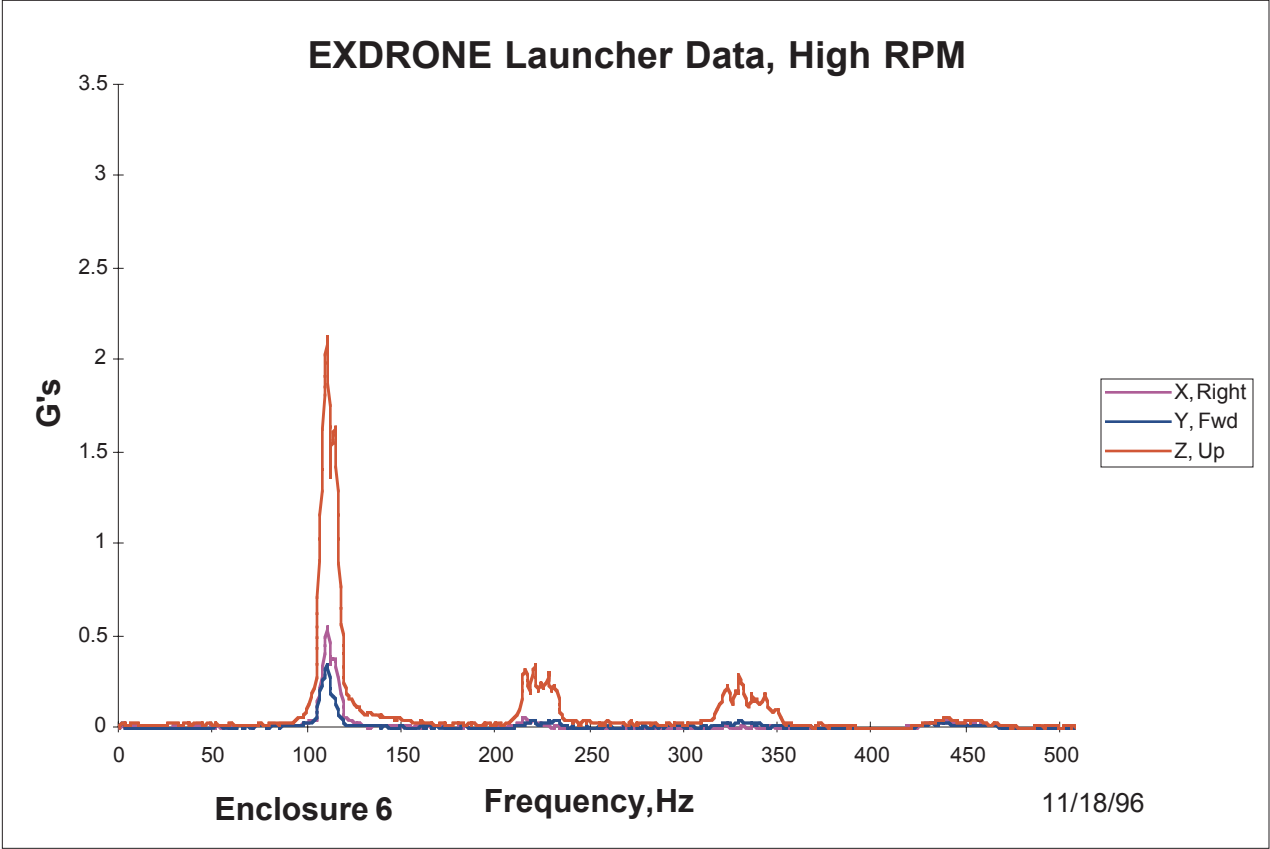
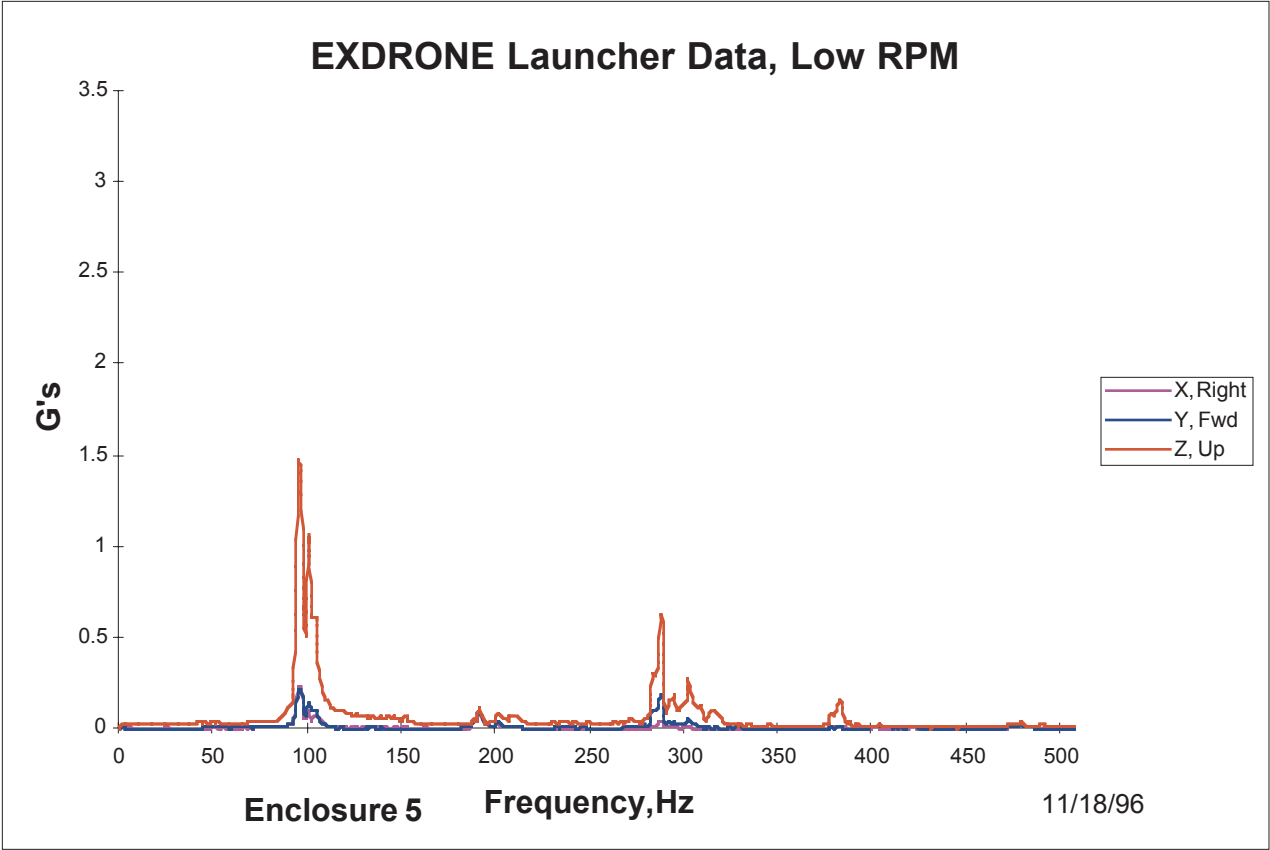


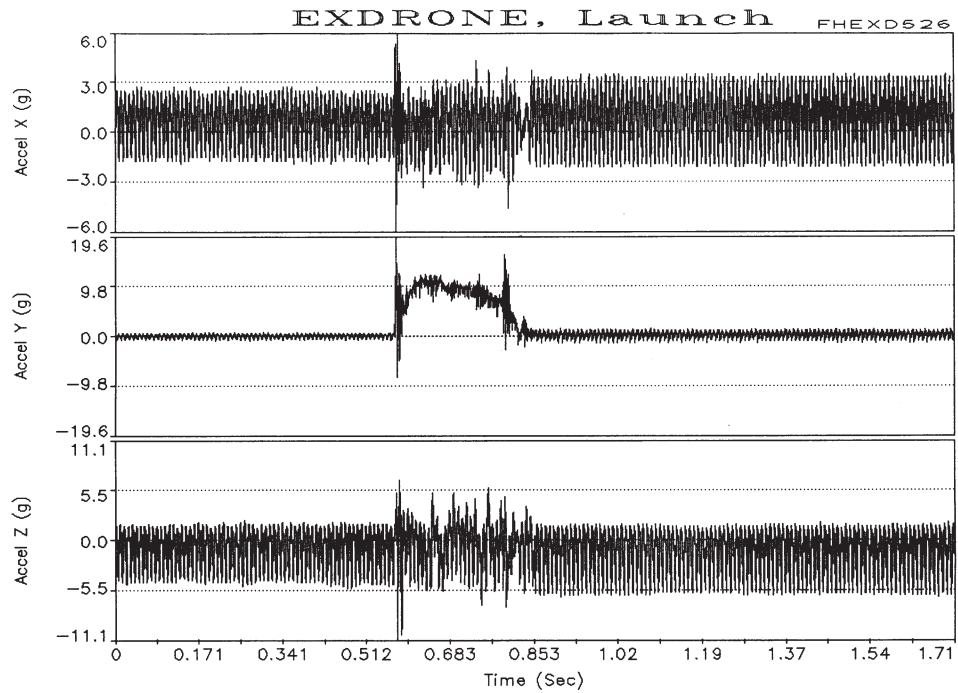
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Enclosure 4

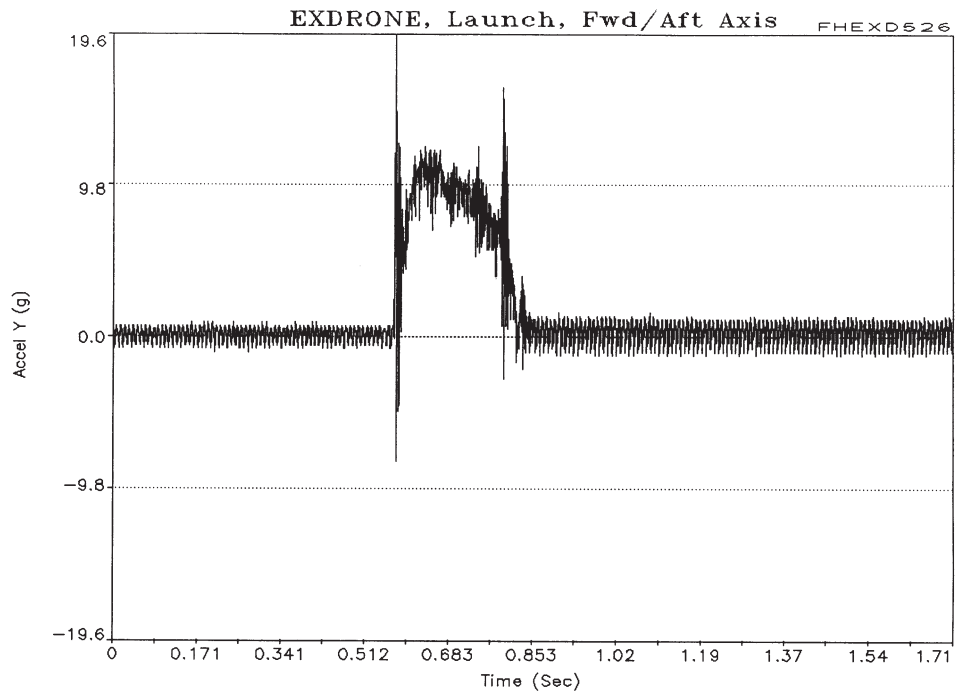
Instrumented Sensor Technology
Tue Nov 05 15:32:42 1996

Samples per event: 4096





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Sample freq:	4800	Samples per event: 4096



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Events in file:	235	Enclosure 8
Sample freq:	4800	Samples per event: 4096

